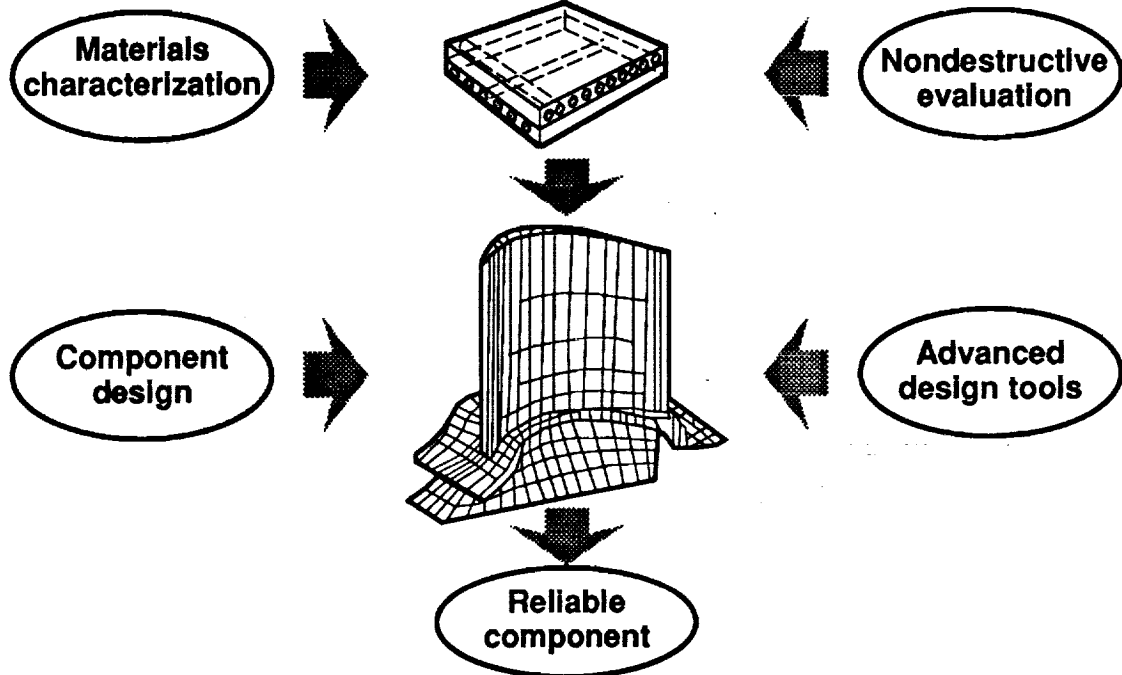


TRANSITION-TO-PRACTICE TECHNOLOGIES FOR BRITTLE MATERIALS

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Four major technologies are needed to bring brittle ceramic composites up to the level necessary for practical application as aerospace materials. These are mechanical testing, nondestructive evaluation (NDE), mechanical design, and life prediction. An advanced design tool, C-CARES, has been developed to assist designers in the mechanical design of structural ceramic components by determining the reliabilities of these components. In situ and in process NDE are being used to enhance/accelerate development of CMC's. As a very minimum both x-ray and ultrasonic imaging needs to be performed for an accurate NDE. In situ and in process NDE also provides validation of analytical models.

Transition-to-Practice Technologies for Brittle Materials

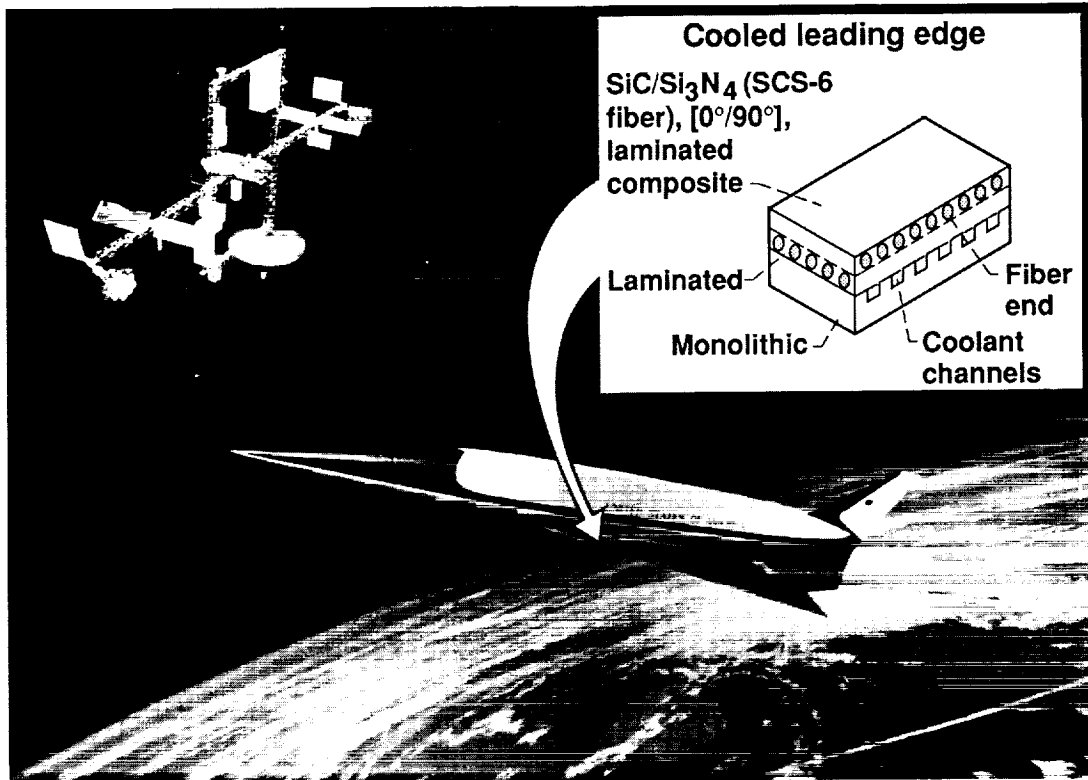


- **Materials characterization and advanced design tools are being used to develop ceramic components with high reliabilities.**

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Transition-to-practice technologies are needed to bring brittle ceramic composites up to the level necessary for practical application as aerospace materials. Two key areas where technologies are being used to develop ceramic composites are Materials Characterization and Component Design. Materials characterization techniques, both destructive and nondestructive, yield information on the material's failure mechanisms, integrity and degradation. This crucial information guides and enhances the development of ceramic composites. Advanced design tools are also being developed to assist component designers with structural ceramic composite component development. These tools strongly influence the design of structural ceramic composite components by determining the component's reliability and life expectancy.

Transition-to-Practice Technologies for Brittle Materials



Advanced high-temperature, low-density composite materials are being developed for use in the next generation of aerospace systems. The High Speed Civil Transport (HSCT), an aircraft for transporting 250 passengers at Mach 3.2 for 5000 n mi and the National Aerospace Plane (NASP), a transportation system that will take off, fly at Mach 25 directly into orbit and land like a conventional aircraft, will require advanced composite materials for both propulsion and structural components.

Transition-to-Practice Technologies for Brittle Materials

- **Mechanical testing**
- **Nondestructive evaluation (NDE)**
- **Mechanical design**
- **Life prediction**

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The four major transition-to-practice technologies are needed to bring composite materials from the current developmental to the practical applications stage needed to develop the HSCT and NASP. The four areas are mechanical testing, nondestructive testing, mechanical design, and life prediction. Mechanical and nondestructive testing are technologies needed for materials characterization. Mechanical design and life prediction are technologies that make use of the materials properties in order to produce reliable, long life components.

Nondestructive Evaluation for Component Development

- **In process NDE- characterizes microstructure and flaw populations that affect strength and life.**
- **In Situ NDE- Performed during testing identifies occurrences of failure mechanisms.**
- **Both provide feedback for materials development and for validating analytical models.**

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Two types of nondestructive evaluation (NDE) are needed for developing ceramic composite components: in situ and in process NDE. In process NDE is done during the development of materials to characterize microstructural and flaw populations that affect strength and life. In situ NDE is performed during testing and is used for identifying the occurrence of failure and the failure mechanism. Both types of NDE provide feedback for materials development and for validating analytical models.

Nondestructive Evaluation Tools for Materials Development

- **X-ray radiography**
- **Ultrasonic imaging**
- **Acoustic emission**

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Many tools are available for performing nondestructive evaluation. The three most important for characterizing ceramic composites are acoustic emission, x-ray radiography, and ultrasonic imaging. Acoustic emissions are ultrasonic signals generated during the actual fracturing of fibers or matrix material. X-ray radiography and ultrasonic imaging are similar to their medical equivalents of x-ray and ultrasound.

In Process NDE Objective

Nondestructively evaluate ceramic composites for microstructure and flaw population that affect strength and life.

- **Cracks**
- **Fiber alignment**
- **Bond quality**
- **Porosity**

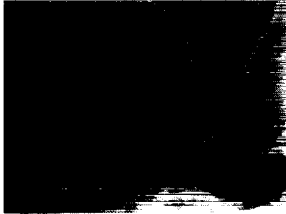
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The objective of in process NDE is to nondestructively evaluate ceramic composites for microstructure and flaw populations that affect strength and life. The most important are cracks, fiber alignment, bond quality variations, and porosity.

Nondestructive Assessment of Impact Damage in CMC Composites

$\text{SiC}_F/\text{Si}_3\text{N}_4$ Ceramic Matrix Composite Laminate

X-ray radiograph

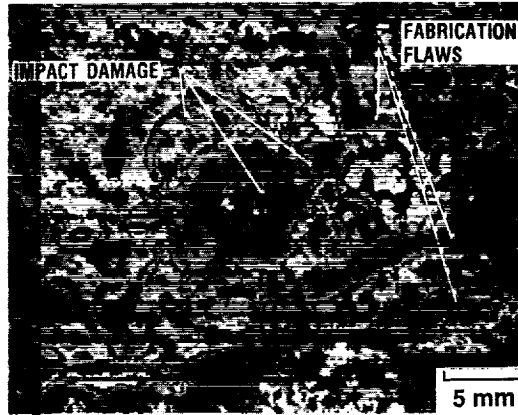


Before Impact



After Impact

Ultrasonic scan Image

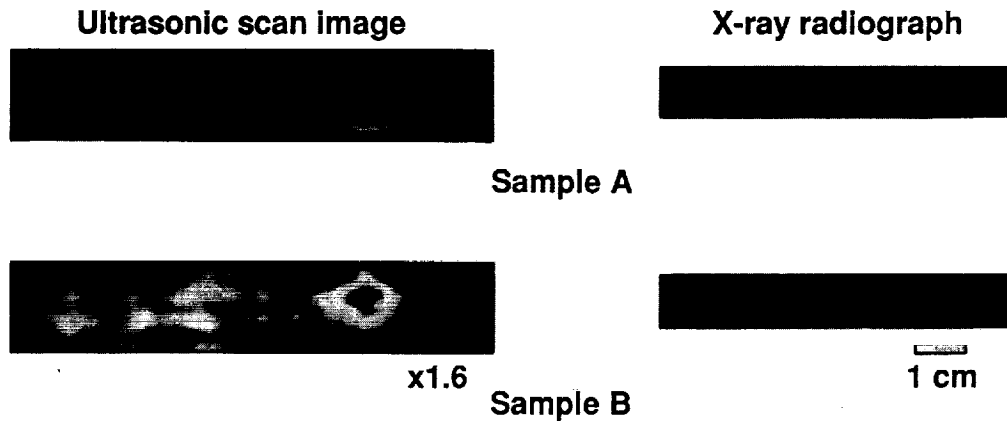


Comparison of radiographs and ultrasonic images shows cracks pre-existing the impact damage, which is confined to delaminations near the impact zone.

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A SiC fiber/ Si_3N_4 composite panel was impacted with a projectile. Before and after x-ray radiographs show cracks pre-existing. The impact damage is confined to the delaminations in the vicinity of the impact zone.

Nondestructive Evaluation of Hot-Pressed SiC Fiber/Si₃N₄ Laminated Composite



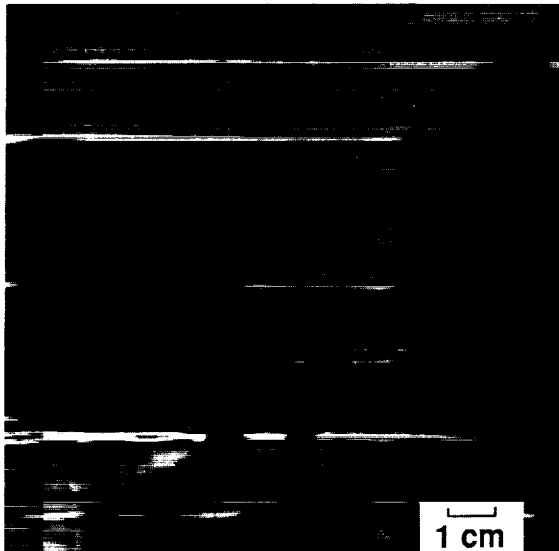
- X-ray images indicate that identically produced samples have similar density structures.
- Light areas in acoustic image identify regions exhibiting "good" bond between lamina.

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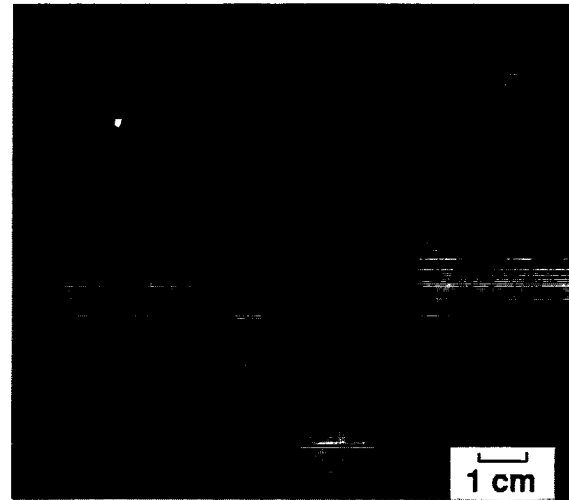
Two similarly produced SiC fiber/Si₃N₄ laminated composite samples have essentially identical x-ray radiographic results. However, the ultrasonic images indicated that the bonding between the lamina is quite different for the two samples. A laminated composite sample that has a good bonding between layers will have strong ultrasonic through transmission signals, which will appear as lighter areas in the image. Sample B has higher (brighter) ultrasonic transmission properties than sample A; therefore, sample B has "good or better" bond between layers.

Nondestructive Evaluation of Nicalon/CAS [0°/90°] Laminated Composite

Ultrasonic scan image



X-ray radiograph



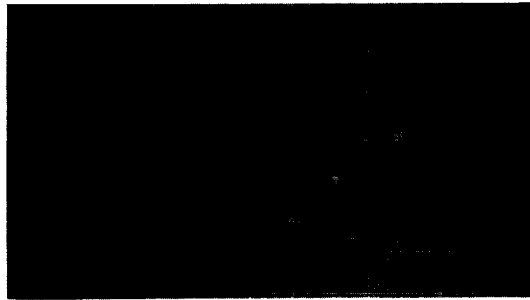
- Ultrasonic and X-ray images reveal low density regions after hot pressing.
- Both images reveal similar features—no debonds or delaminations are present.

CAS = Calcium aluminosilicate glass

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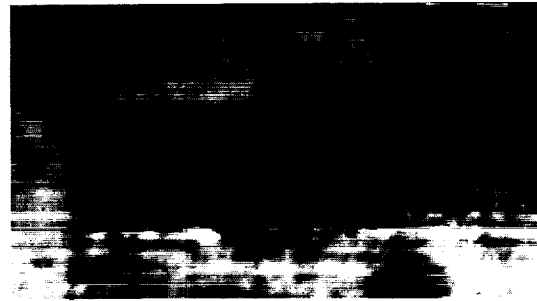
X-ray and ultrasonic analysis may yield identical results. The dark areas of the ultrasonic image correspond with the areas of low density (high porosity) in the x-ray radiograph.

Nondestructive Testing of Laminated Ceramic Composite Panels



1 cm

X-ray image



Ultrasonic image

- **X-ray image reveals misaligned/bowed fibers.**
- **Ultrasonic image reveals isolated delaminated (dark) regions.**
- **Images obtained before and after testing provide crucial information on failure mechanisms.**

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The x-ray radiograph of a laminated SiC fiber/Si₃N₄ composite panel indicates that the fibers are misaligned or bowed. The ultrasonic image reveals dark regions where there is poor bonding between lamina.

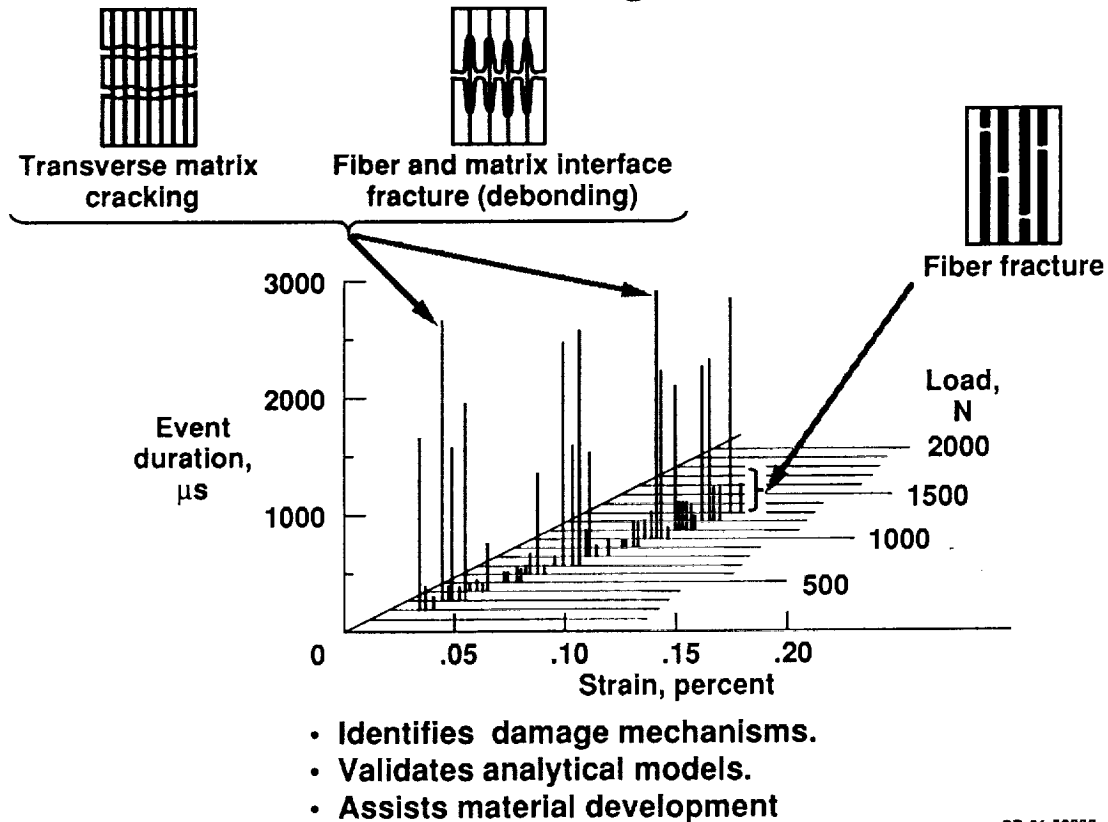
In Situ NDE Objective

- **Identify the occurrence of failure mechanisms during loading.**
-
- **Transverse matrix cracking**
 - **Fiber fracture**
 - **Fiber interface failure**

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One objective of in situ NDE is to identify the occurrence of failure mechanisms during loading. These mechanisms are transverse matrix cracking, fiber fracture, and fiber interface failure.

Acoustic Emissions During Mechanical Testing



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During loading fracturing fibers and matrix material generate acoustic signals that may be grouped according to the duration of the signal. Acoustic emissions that have a long duration are due to transverse matrix cracking or fiber/matrix interface debond. Short duration acoustic signals are indications of individual fiber fracture. The occurrence of damage mechanisms is used to validate models and assist in the material development.

Ceramic Matrix Composite Design Analysis Objective

**Develop and refine analytical methods and
computer codes for predicting**

- **Fast fracture**
- **Component life**

**for laminated ceramic composites used as
structural components in aerospace applications
that entail high-temperature environments.**

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Ceramic materials are brittle. The mechanical failure of these materials follows probabilistic failure theories. Therefore, probabilistic methods need to be incorporated in the design when developing a specific component. Analytical methods and computer codes are being developed for predicting fast fracture failure and life remaining of laminated ceramic composite components.

Computer Program Developed

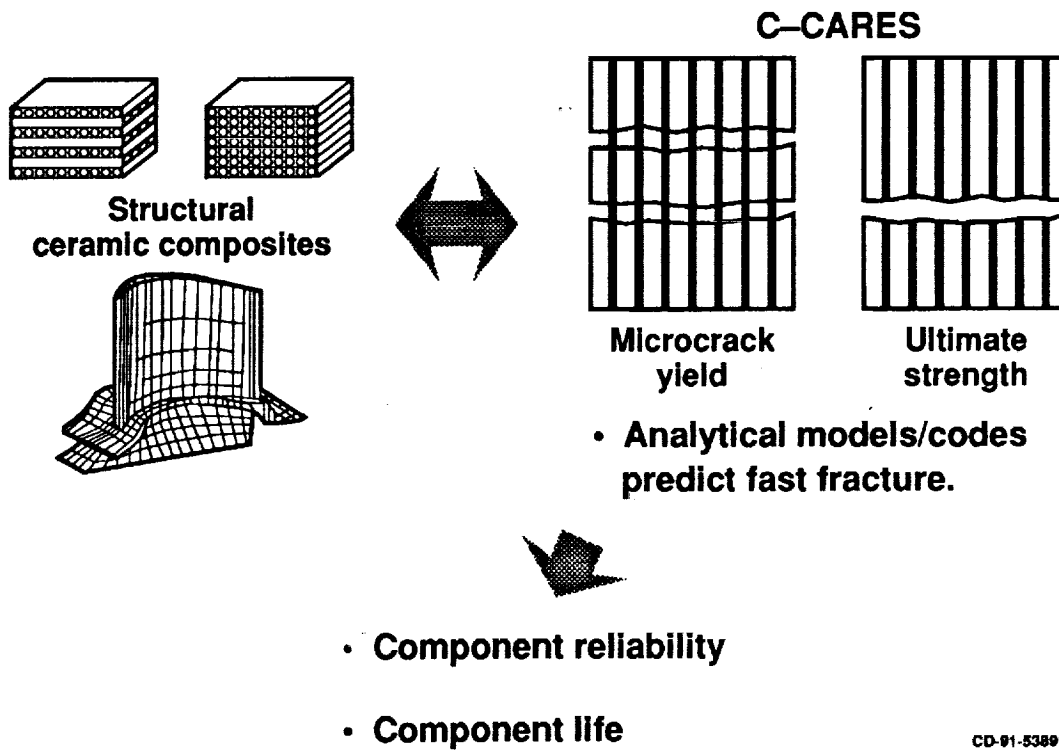
C-CARES:

Composite Ceramic Analysis and Reliability Evaluation of Structures

CD-91-53890

A computer program has been developed to predict fast fracture of ceramic composite components. The program is available as Composite Ceramic Analysis and Reliability Evaluation of Structures or C-CARES.

C-CARES: A Needed Design Tool



C-CARES identifies the microcrack yield and ultimate strength of structural ceramic composites. Since C-CARES is based on probabilistic failure theories that represent these advanced ceramic composites, an overall component reliability is determined.

Status of and Plans For C-CARES Code

- **First version coupled to MSC/NASTRAN.**
- **Ply level analysis included.**
- **Three modes of failure: transverse to fiber, parallel to fiber, and in-plane shear.**
- **Extend theory to include time dependent mechanisms that determine component life.**

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The first version of the C-CARES computer code has been coupled to a finite-element analysis program, MSC/NASTRAN. The stress states of components determined from MSC/NASTRAN are used directly by C-CARES. C-CARES analysis can be done at the ply level and permits three modes of failure: transverse to the fiber, parallel to the fiber, and in-plane shear. The C-CARES code is being extended to include time dependent mechanisms that determine component life.

CONCLUSION

The four major technologies needed to bring ceramic composites up to a level for practical application as aerospace materials are: mechanical testing, nondestructive evaluation, mechanical design, and life prediction. An advanced design tool, C-CARES, has been developed to assist designers in the mechanical design of structural ceramic components by determining the reliabilities of these components. In situ and in process NDE are being used to enhance/accelerate development of CMC's. As a very minimum both x-ray and ultrasonic imaging needs to be performed for an accurate NDE. In situ and in process NDE also provide validation of analytical models.

- Mechanical design
- Nondestructive evaluation
- Mechanical testing
- Life prediction

Are technologies needed to develop CMC's for practical aerospace applications?

Advanced design tool, C-CARES, may be used to determine reliabilities of structural ceramic components.

In Situ and in process NDE enhance/accelerate development of CMC's, and provide validation of analytical models.

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